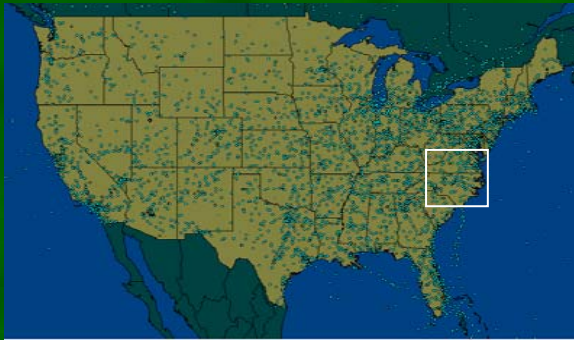




Transforming the National Airspace System



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May 20, ICNS Conference

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Properties of Complex Adaptive Systems

- **Capacity - Delay**
- **Capacity – Delay – Safety**
 - **ROT Safety Limitations**
 - **Wake Vortex Safety Limitations**
- **Observations and Recommendations**



CAS do NOT Transition Linearly

- **The NAS IS A Complex Adaptive System (CAS)**
- **CAS Systems are Highly Non-Linear and the benefits of any given Sub-System are NOT Additive!**
- **This CAS has STRONG Economic, Multi-Actor, and Safety Regulatory Properties**
- **Flight DELAYS are not Compelling Enough to Significantly FIX a Transportation Network that is in DECLINE!**
- **The System Adapts to WHAT is Measured**
- **Delays are being Managed by DECREASING SAFETY MARGINS**



New Regulations, Technology

- **Safety is the ONLY Compelling Reason to Transform the NAS**
- **Most of the Capacity, Productivity and Safety Gains come from the Installation and Regulatory Benefits of Flight Deck Equipment**
- **A New Regulatory Environment MUST be Coordinated with the Insertion of Universal Data-Links and Aircraft Self-Separation in Closely Spaced Airspace**
- **High-Capacity Airports MUST Provide an Economically Efficient means for SAFE Demand Management**



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Capacity and Safety are Critically Related





Capacity and Delay

- **System Capacity is Primarily Limited by Network Runway Availability**
- **ATC Workload is an important Secondary Limitation**
- **Runway Maximum Capacity is a function of Aircraft Landing Speed and Runway Occupancy Time (ROT)**
- **Delay is a Non-Linear function of Demand to Maximum Capacity Ratio**
 - **Stochastic FCFS System**
 - **Queuing Theory Applies**
- **Major Hub Airports are Over-Scheduled**



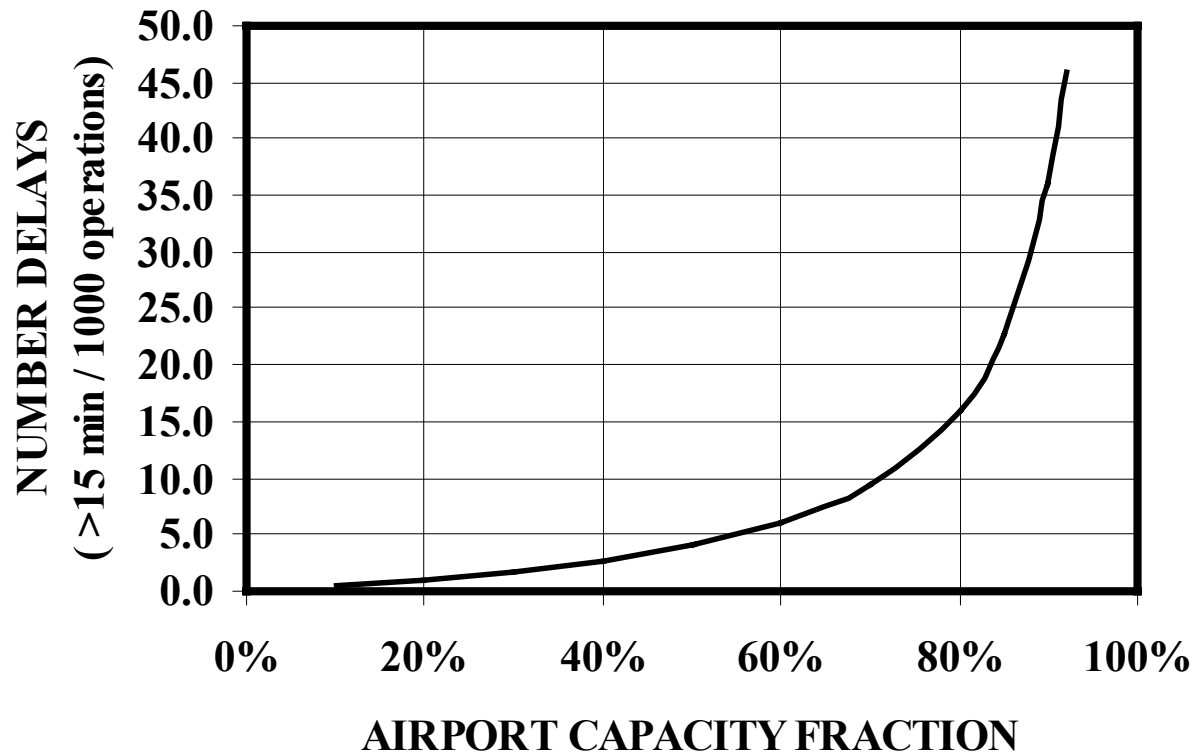
Operational Capacity is a Limited Commodity

- $C_{MAX} = 2 C_{AR MAX} S \sum_i (XG)_i R_i \quad \{Airports\}$
 $-\sum_K A_K(t) \{Airspace Management Intervention\}$
 - $S = f(\text{Safety}, \tau_{ATC}, \text{Wake Vortex, etc.}) \sim 0.6$
- $A_K(t) = (A/C_{REQUEST} - A/C_{ACCEPT}) \sim [0 \text{ to } >1,000]$
 - $A_K(t) = f(\text{GDP:Weather, Sector Workload Constraints})$
- $C_{AR MAX} \sim 64 \text{ Arrivals/Hour (set by Runway Occupancy Time)}$
- $R_i = \text{Number of Runways at } i^{\text{th}} \text{ Airport}$
- $XG_i = \text{Airport Configuration Factor at } i^{\text{th}} \text{ Airport}$
- $i = 1 \text{ to } N$, where N is approximately 60 Airports
- $K = 1 \text{ to } M$, where M is typically much less than 100 Sectors



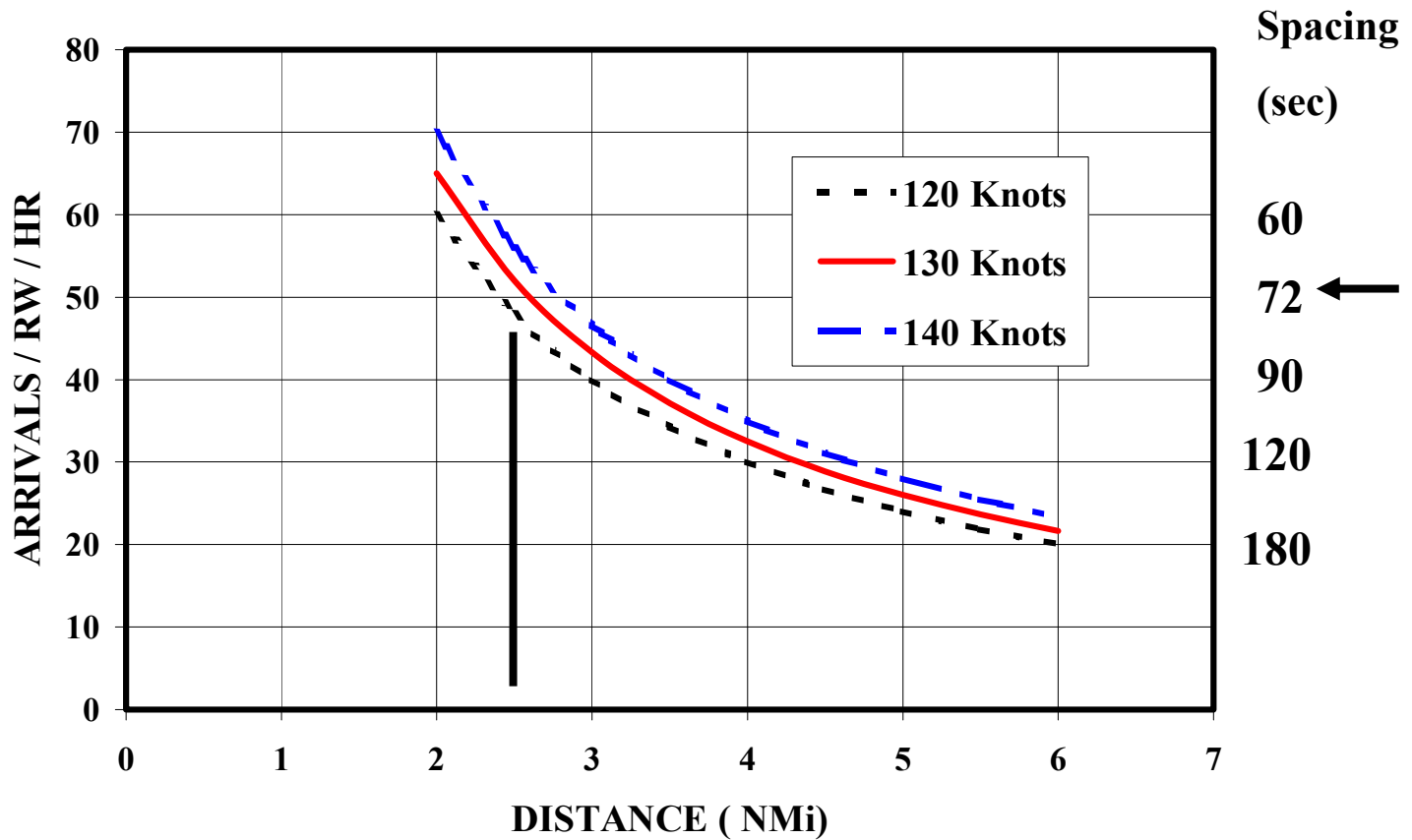
ATS Delays Grow Exponentially with Increasing Capacity Fraction

PREDICTED DELAY vs. CAPACITY FRACTION



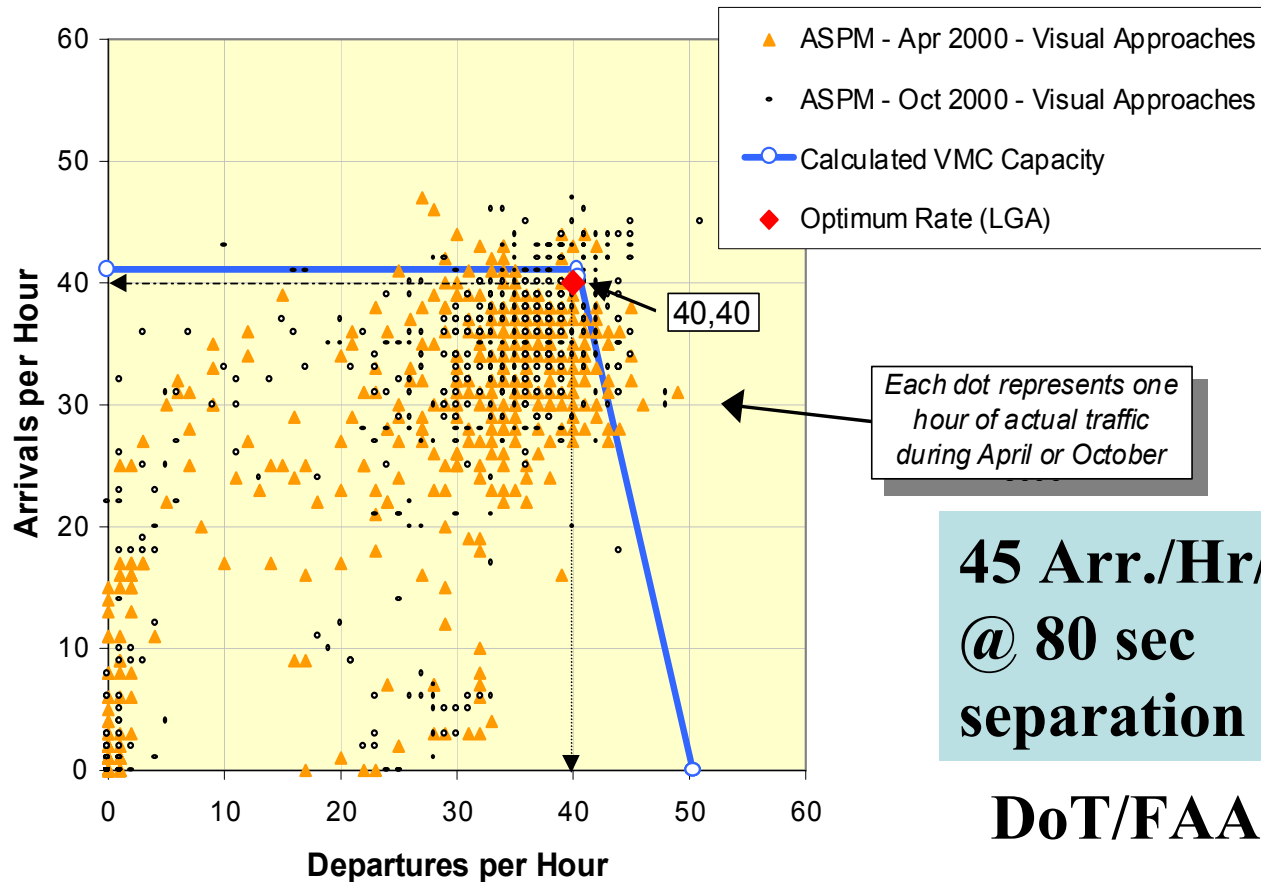


Aircraft Arrival Rate: Distance-Time Relationship





New York LaGuardia Airport Arrival- Departure Spacing VMC

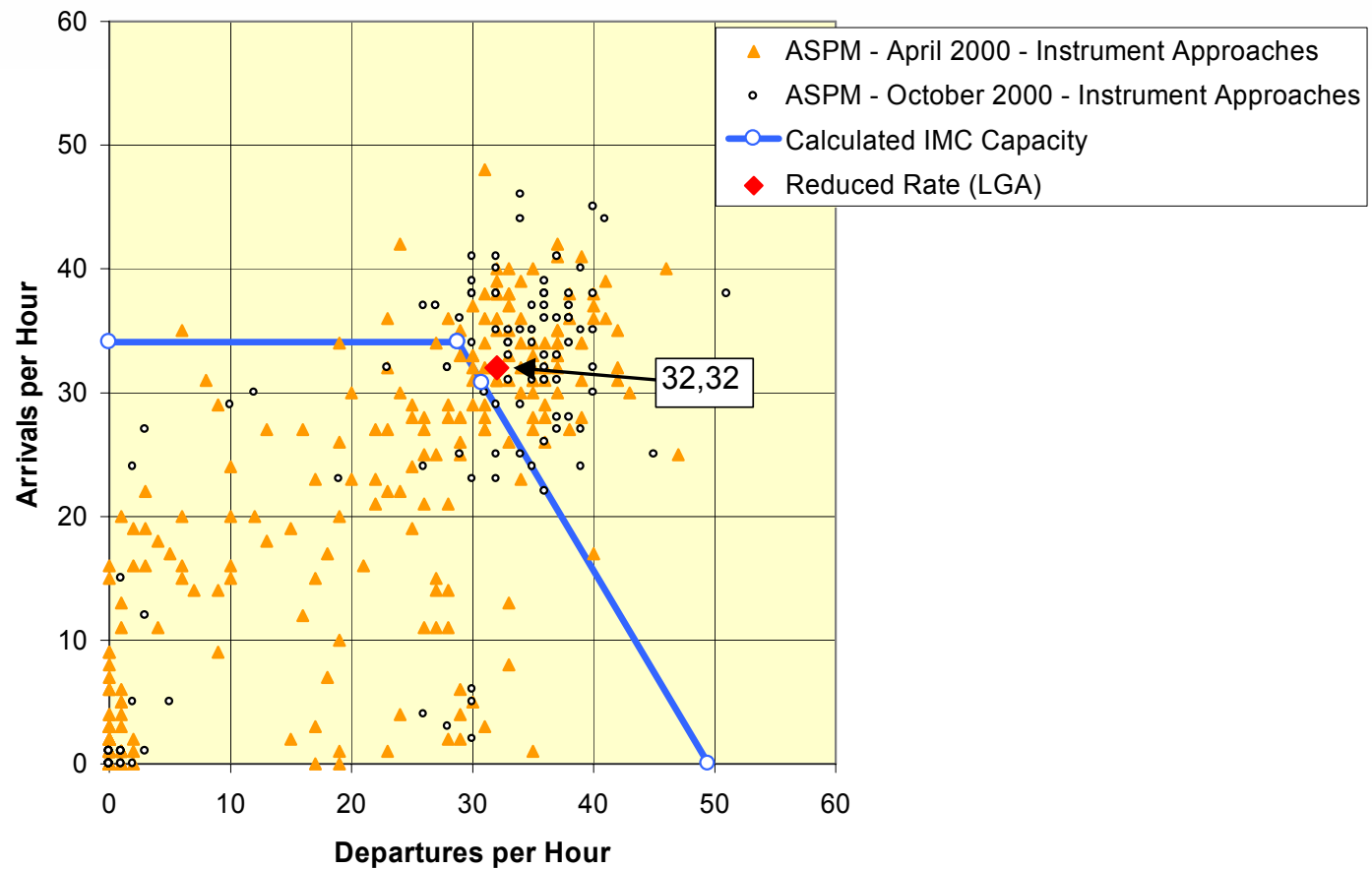


**45 Arr./Hr/RW
@ 80 sec
separation**

DoT/FAA

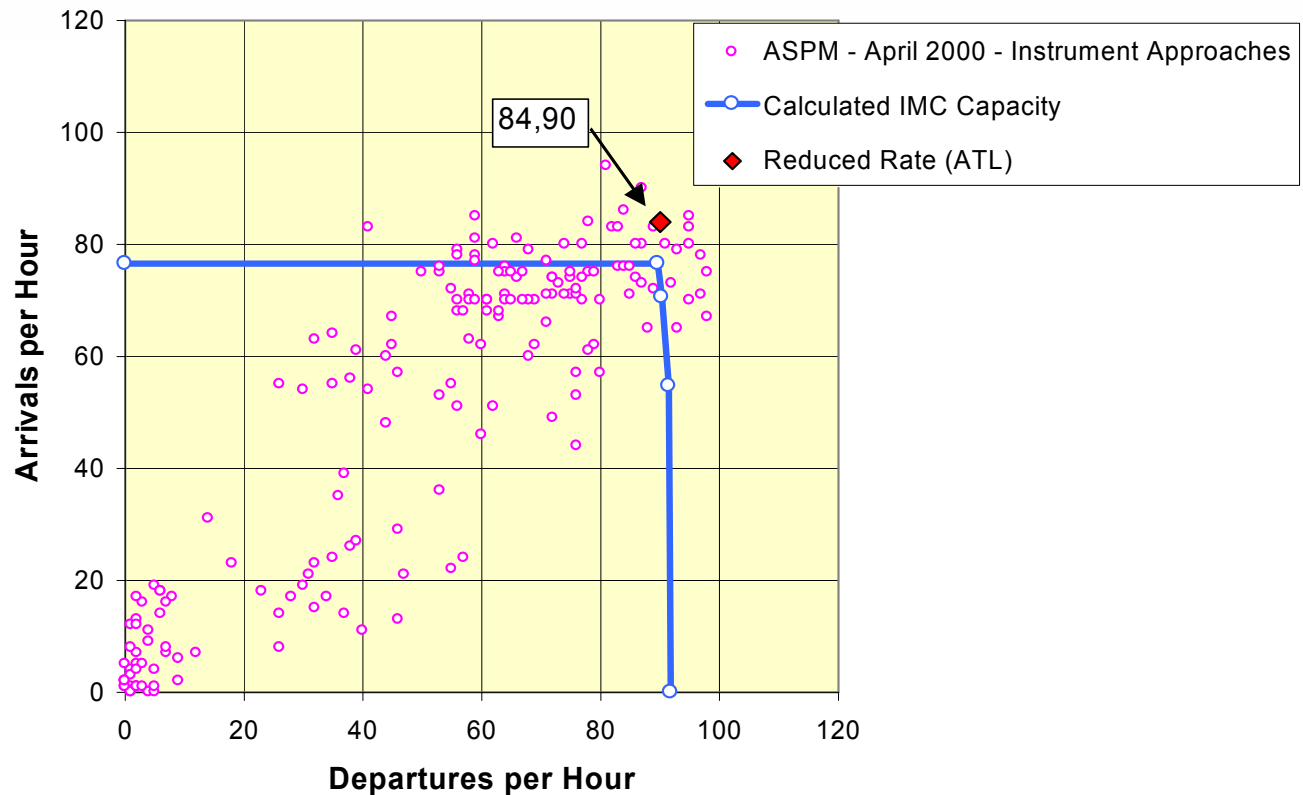


LGA Arrival - Departure IMC





ATL Arrival - Departure IMC





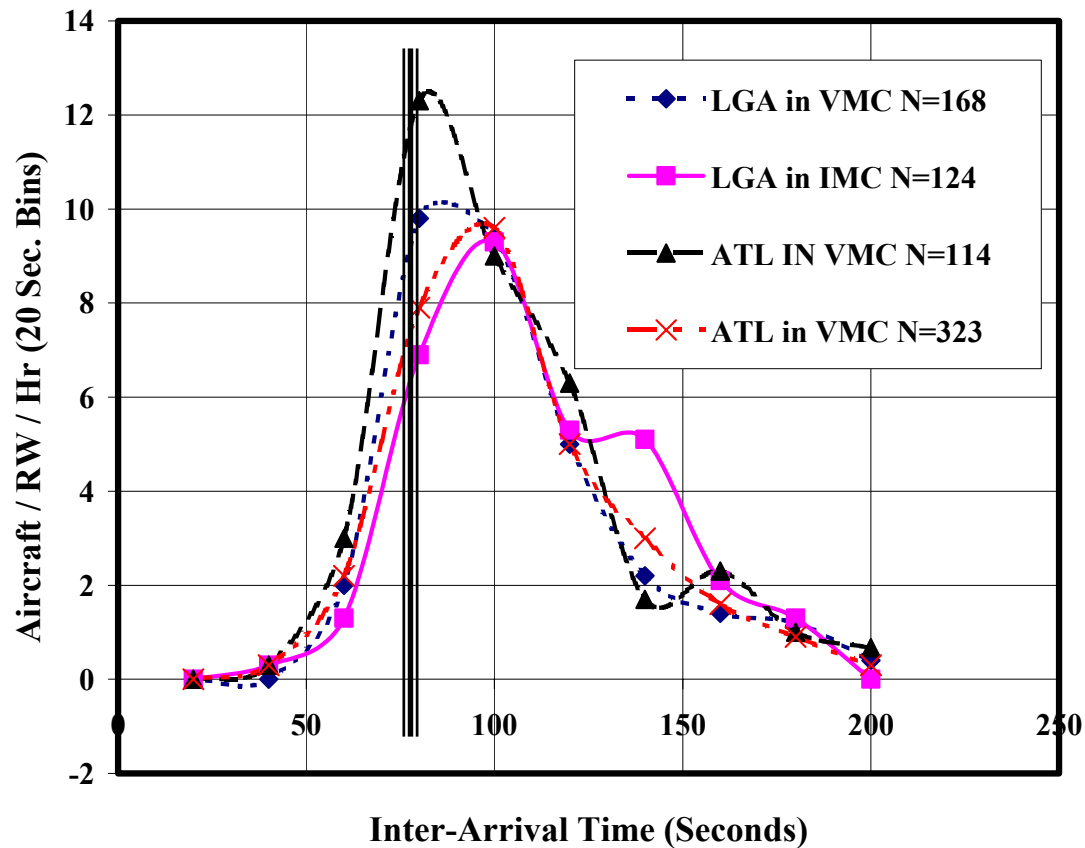
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ATL and LGA Inter-Arrival Time in IMC and VMC:32 - 39 Ar/Rw/Hr

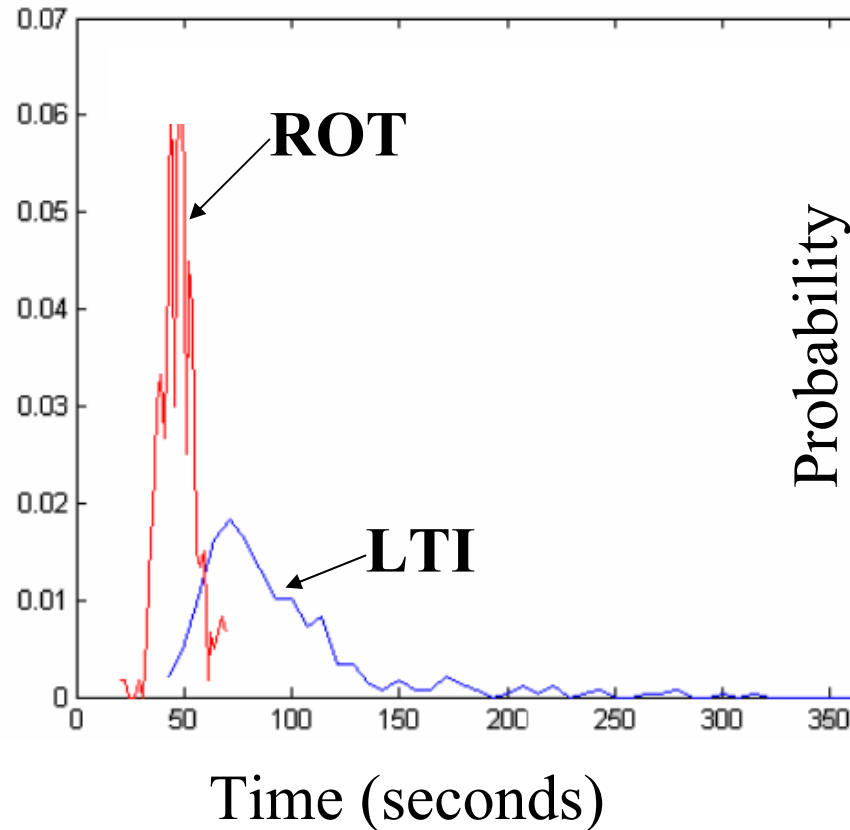
LGA & ATL Arrival Histograms





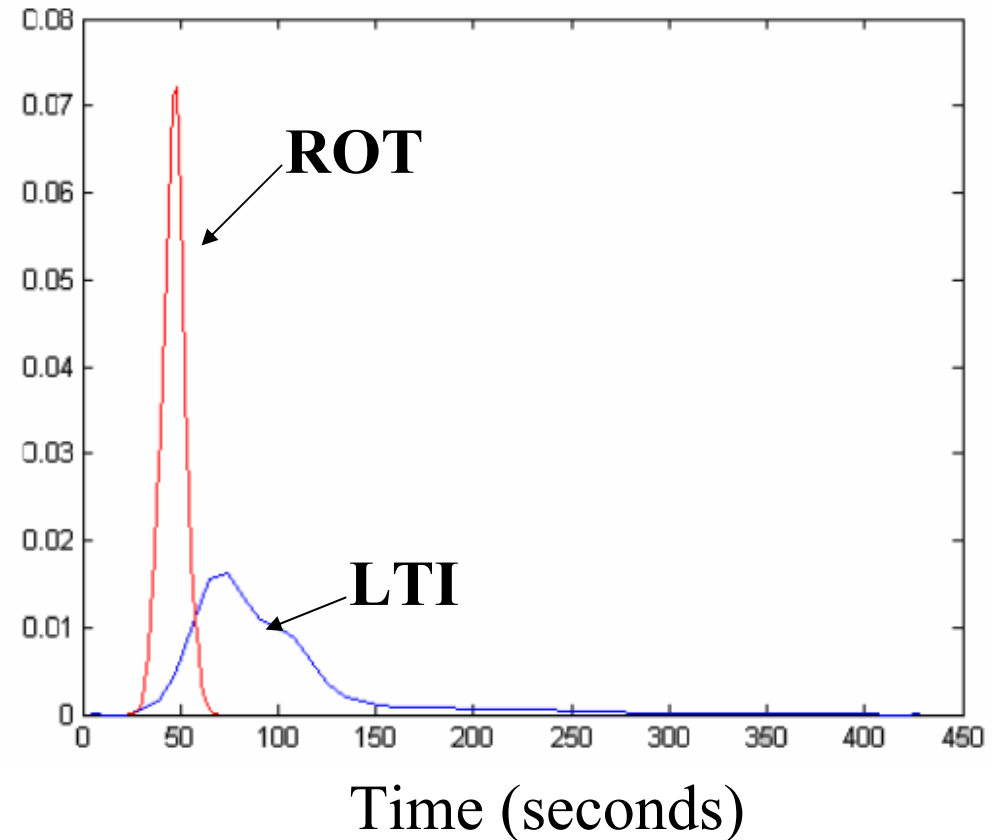
ATL Runway Occupancy and Landing Time Intervals

Observation



LTI: Landing Time Interval;

Simulation Result

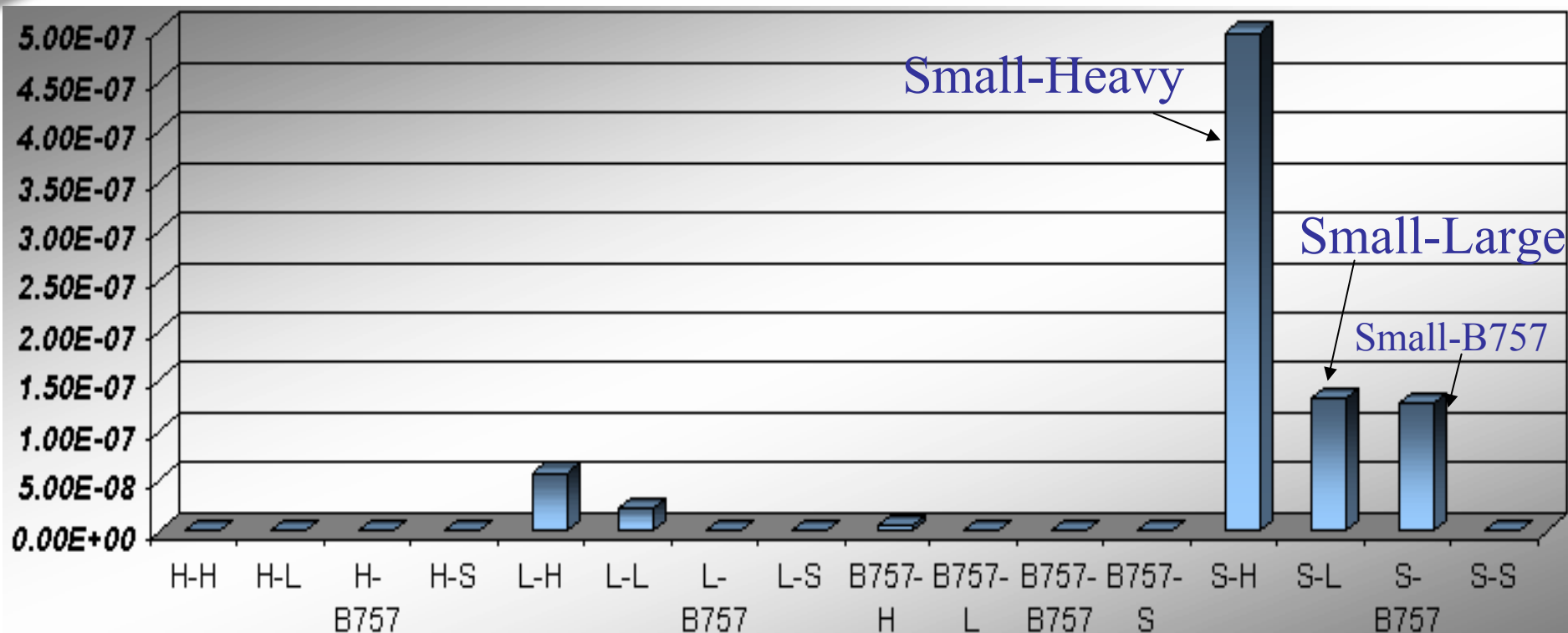


ROT: Runway Occupancy Time



ATL Collision Probability

Collision probability per SRO for each combination



Leader - Trailer



Crowded Terminal Area



Boeing 737-522

Los Angeles - International (LAX / KLAX)

USA - California, February 13, 1999

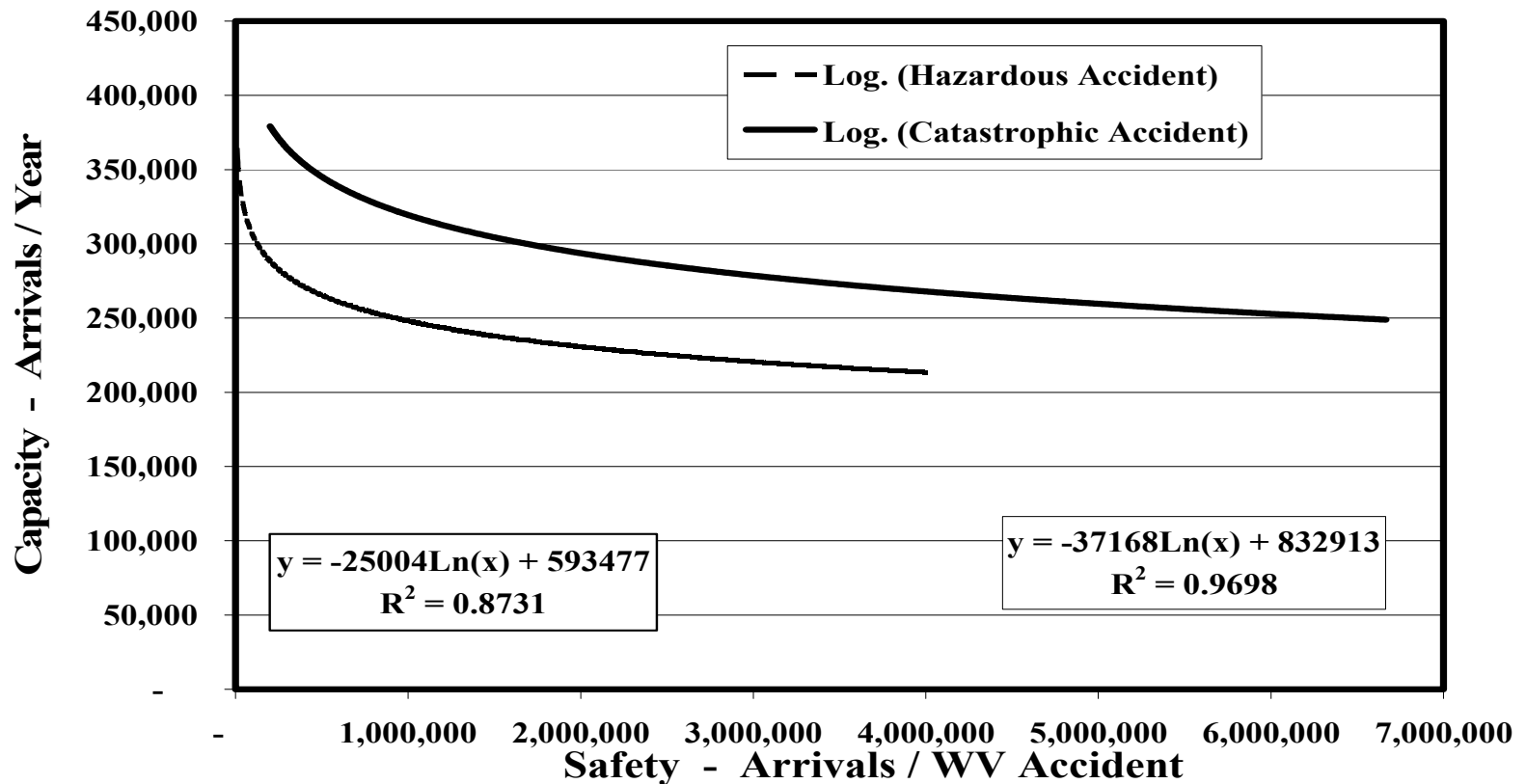
**N930UA UA 737 approaches runway 25L in front of AA 763
(N39356) for runway 25R.**

Photo Copyright AirNikon



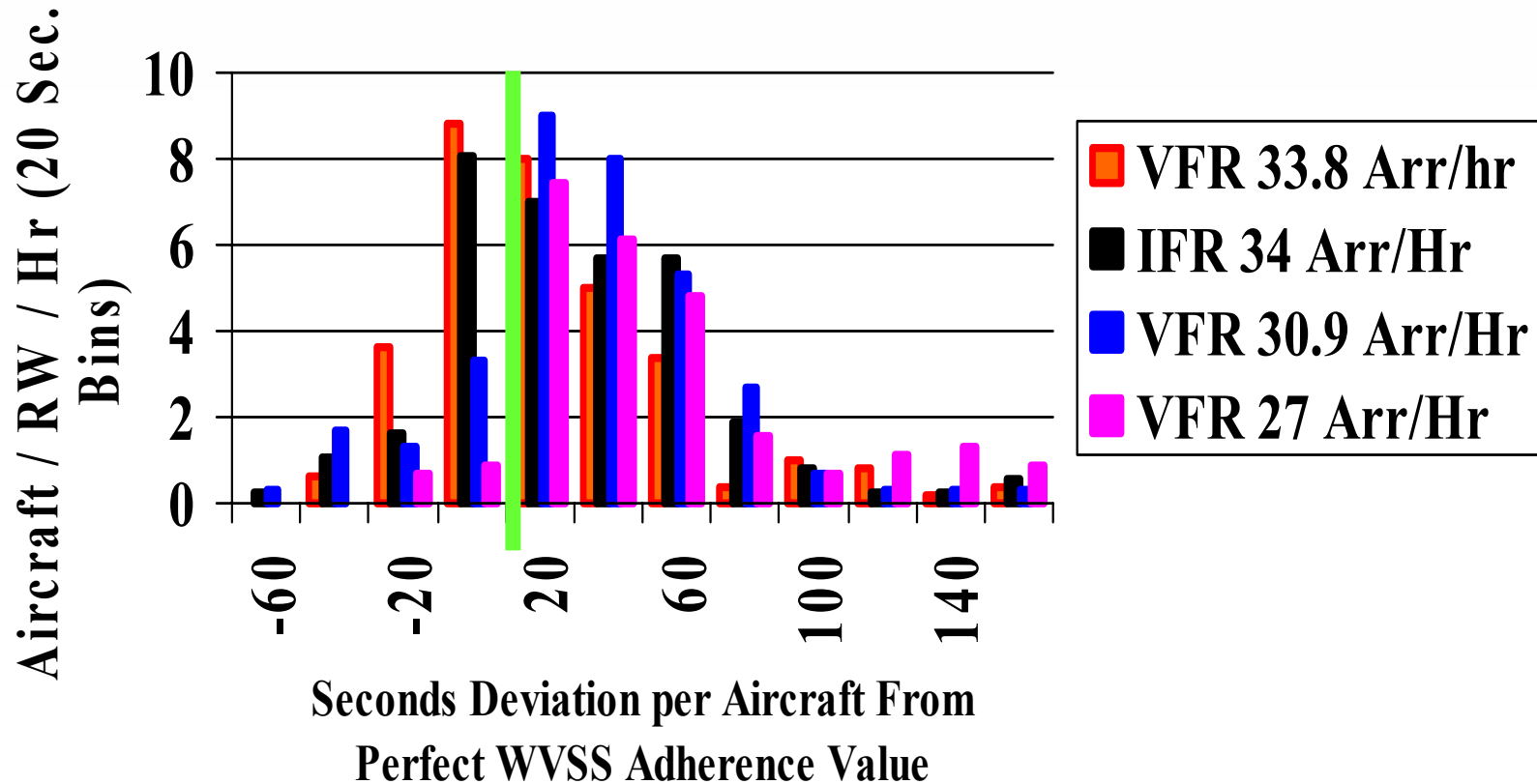
Wake Vortex Accident Rate in Safety-Capacity Coordinates

Single Runway Estimated Wake Vortex Accident Rate
50% Mix B747 & B737: S-Wake Calculation





Wake Normalized Aircraft Time Separation: LGA in VMC & IMC





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FAA Investment Analysis Primarily focus on Capacity and Delay

- OMB requirement to have a B/C ratio > 1 leads to a modernization emphasis on Decreasing Delay
- In an Asynchronous Transportation Network operating near it's capacity margin, Delay is Inevitable
- Delay Costs Airlines Money and is an Annoyance to Passengers BUT
 - is Usually Politically and Socially Acceptable



Central Research Question

- **Both Safety and Efficiency Concerns lead us to the conclusion that the network should be operated as a Synchronous System**
 - with economic incentives to use the largest aircraft affordable
- **Time Window Auctions at Airport Metering Fix may provide the economic incentives necessary to maximize Network Capacity**
- **Central Research Question:**
 - **How Synchronous Can We Make this System?**



Hypothesis: Most Major Changes to the NAS have been due to Safety Concerns

- **1960's Mandated Introduction of Radar Separation**
- **1970's Decrease in Oceanic Separation Standards Required a Landmark Safety Analysis**
- **1970's Required A/C Transponder Equipage**
- **1970's Required A/C Ground Proximity Equipage**
- **1990's Required A/C TCAS Equipage**
- **1990's Required A/C Enhanced Ground Prox. Equipage**
- **1990's TDWR & ITWS Introduction**
- **1990's Mandated Development of GPS/WAAS**



Observations – NAS Safety

- **We are approaching the Point that the existing system may be demonstrably less safe (at current and future capacity fractions) than a new, more synchronous, aircraft FMS/ADS-B separation based system**
- **System is Safe BUT Safety Margins are Diminishing!**
- **This case has not been Analyzed nor even Suggested to date!**



Proposed Grand Experiment/OPEVAL to FOCUS Efforts

- **FY 2008 One Year of Night Operations**
 - **12pm to 8 am**
- **DAG-TM + aFAST+CDM + WV**
- **Entire US Air Cargo Fleet**
- **Inter-Agency IPT**
 - **DoT, NASA, FAA, DoD, NTSB, Boeing, CAA airlines**

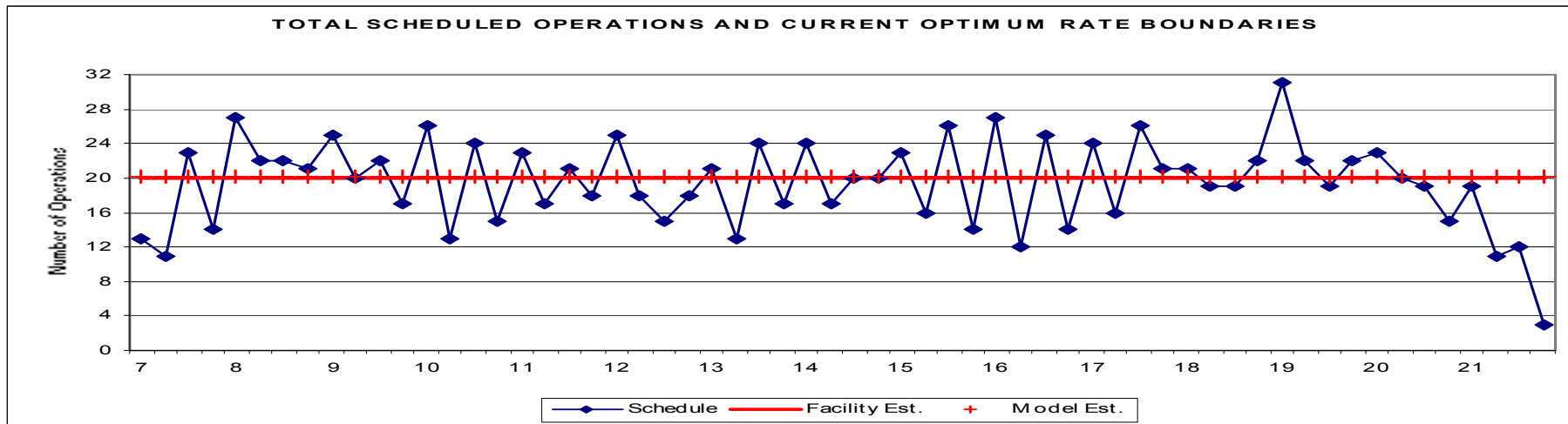
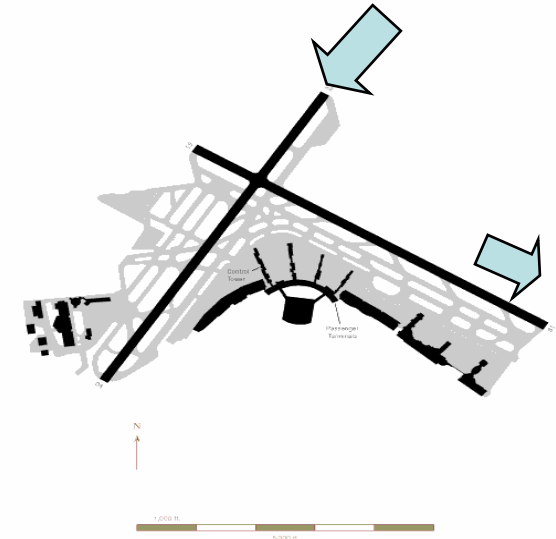


- **BACKUPS**



NY LaGuardia: A non-Hub Maximum Capacity Airport

- 1 Arrival Runway
- 1 Departure Runway
- 45 Arrivals/Hr (Max)
- 80 Seconds Between Arrivals
- 11.3 minute Average Delay
- 77 Delays/1000 Operations
- 40 min./Delay





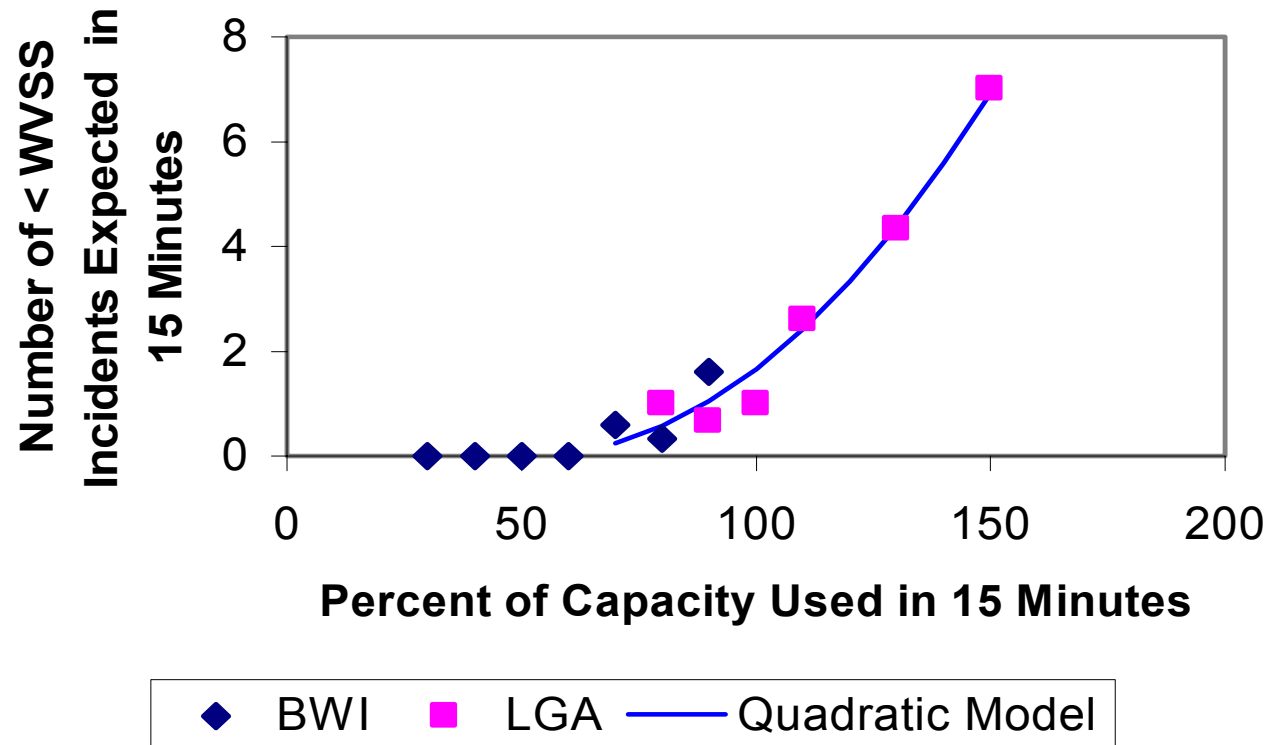
Capacity-Delay-Safety

- **ATM System Safety and Capacity are Non-Linearly Related**
- **Wake Vortex Separation sets the Current System Capacity Limit**
 - **Safety Limitation**
- **ICAO System Safety Goal is 10^{-9} / Operation**
- **Small number Statistics leads us to use Accident Precursors as Safety Indicators**
- **Safety Analysis must be Analytical**



Observed WV Separation Violations vs. Capacity Ratio

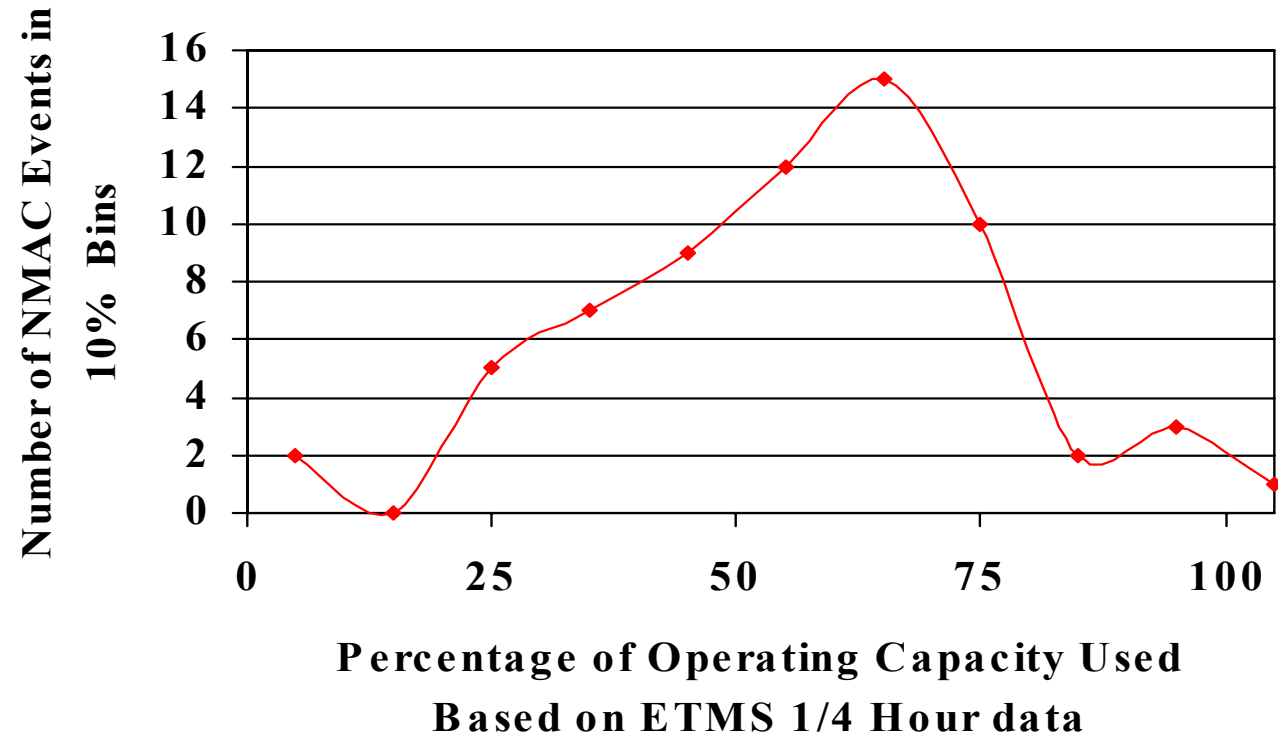
Figure 6-5
Ratio of Incidents to Capacity Used





13 Years of Near Midair Collision reports show Similar Correlation with Capacity

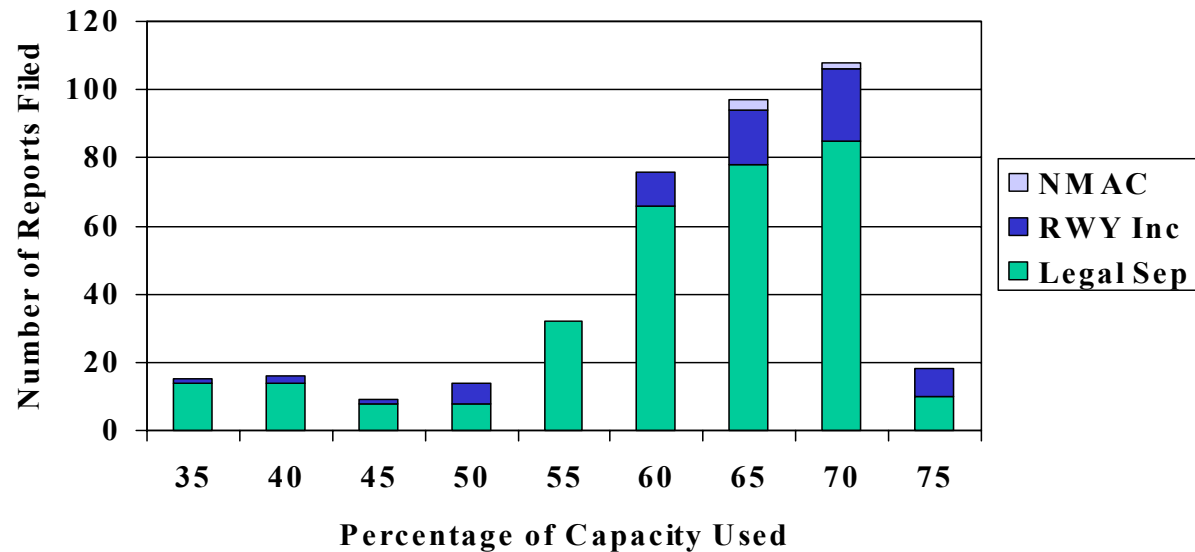
Figure 6-21
NMAC Events at Top 31 Airports Correlated With Capacity Used





Accident Pre-Cursor Incidents seem to Indicate a Trend

Figure 6-19
ATL, BWI, DCA, & LGA Historical Reports 1988-2001
Correlated with Percentage of Capacity Used



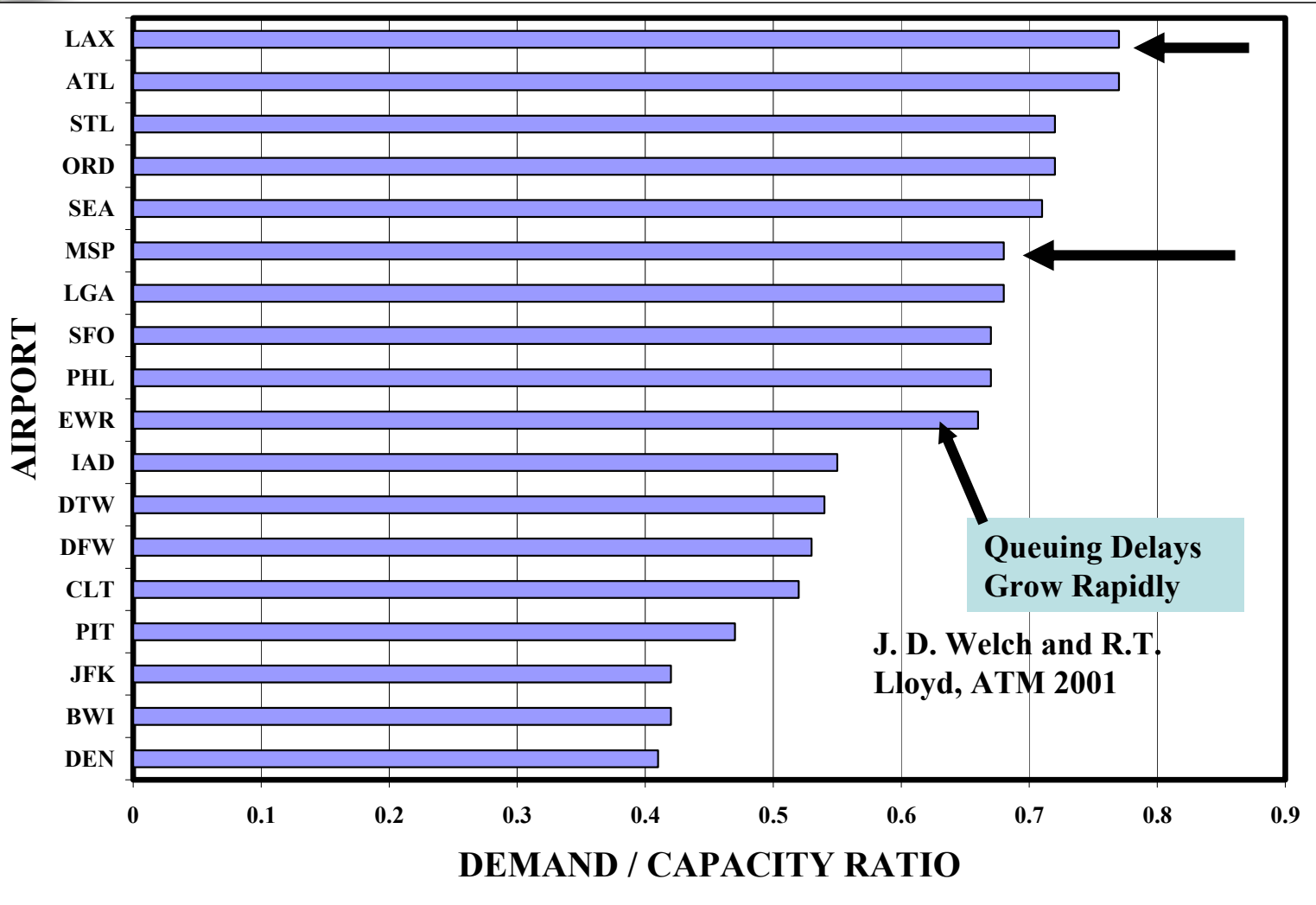


System Network Effects

- **Aprox. 10 Major Hub Airports are Operating at D/C max > 0.65**
- **Delays at these Airports spread Non-Linearly throughout the Network**
- **Runway Additions at one Airport May have Little Network Effect**
- **System-wide improvements have a Larger Effect than Individual Airport Improvements**

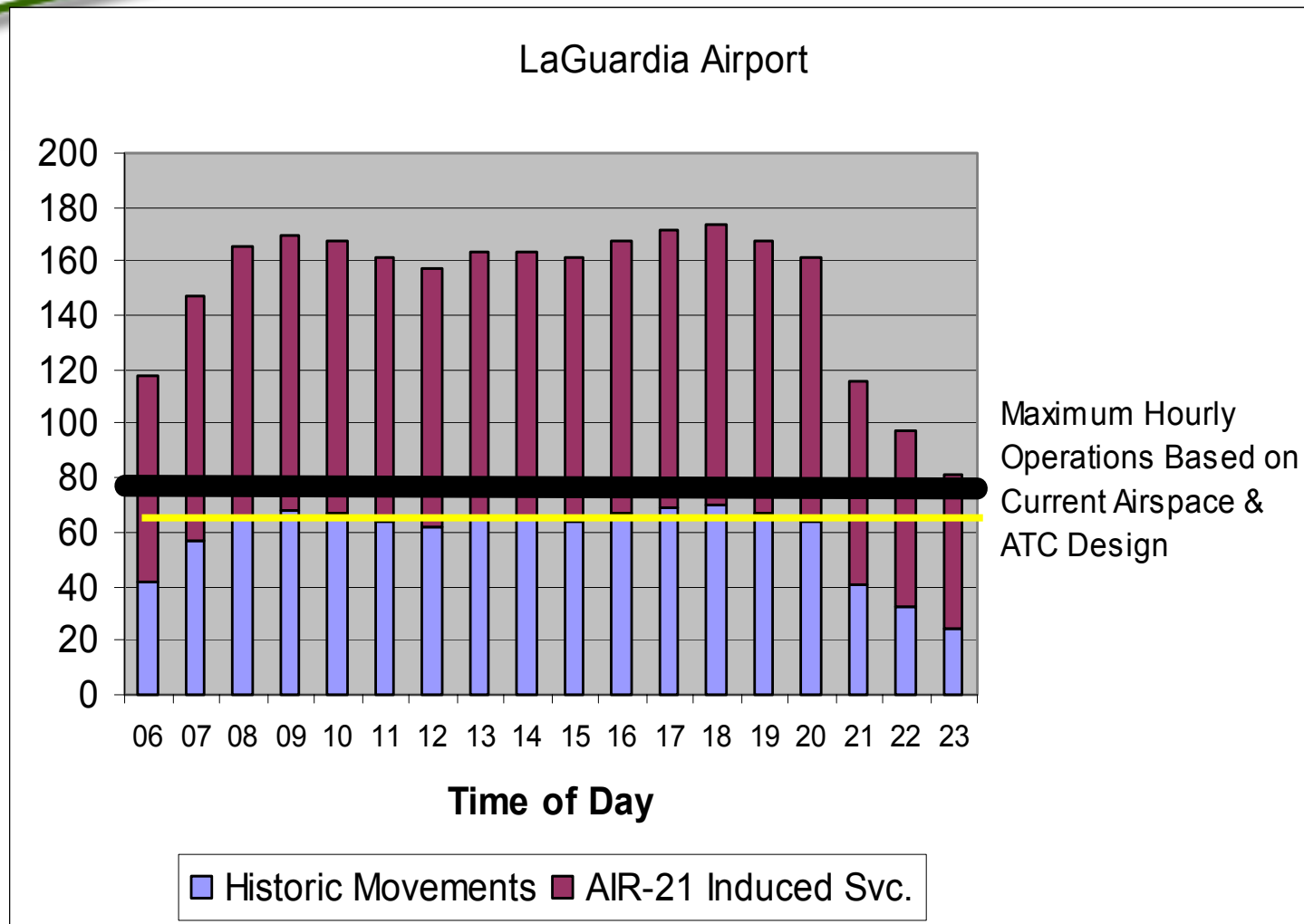


Major US Airport Congestion





The Semi-Regulated Market Does Not Act to Minimize Delay: LGA Air 21 Impact



Source: William DeCota, Port Authority of New York



FAA Barriers to Change

- **FAA has an Operational and Regulatory Culture**
 - **Inclination to follow training that has seemed to be Safe in the Past**
- **Limited Budgets since 1992 have Prevented Achieving a Critical Mass for Change**
- **Assumption that Aircraft Equipage would be Benefits Driven did not account for Lack of a Bootstrapping Requirement**